

Overview of Selected Issues Associated with the Potential for Large Scale Commercial Deployment of Carbon Dioxide Capture and Storage Technologies

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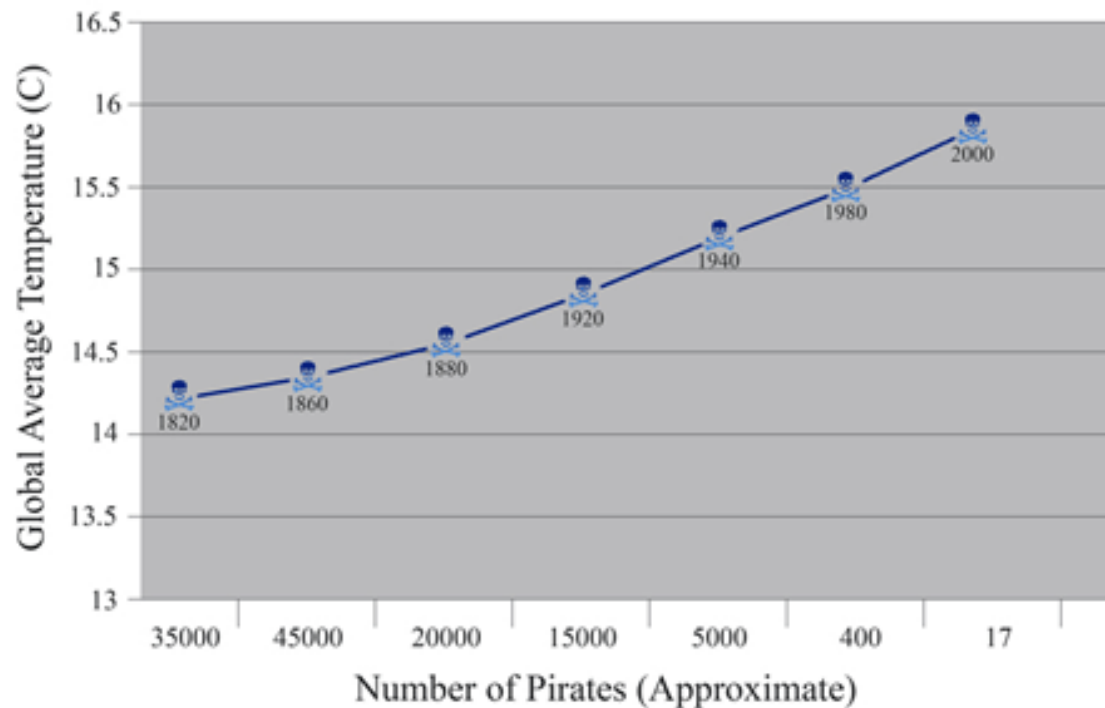
**Indiana Carbon Capture and Sequestration Summit
September 3, 2008**

Key Points

- ▶ Climate change means more than a “warmer world” and melting polar ice caps.
- ▶ Stabilizing the concentration of CO₂ means fundamental change to the global energy system and therefore fundamental change to the entire global economy.
- ▶ Technology is essential to addressing climate change and controlling the cost of doing so.
- ▶ Cost will affect the level at which CO₂ concentrations are stabilized.
- ▶ There is no “silver bullet” for addressing climate change nor is there a “silver bullet” for managing the negative consequences of a changing climate.

Dispelling a Persistent Climate Change Myth

Global Average Temperature Vs. Number of Pirates



www.venganza.org

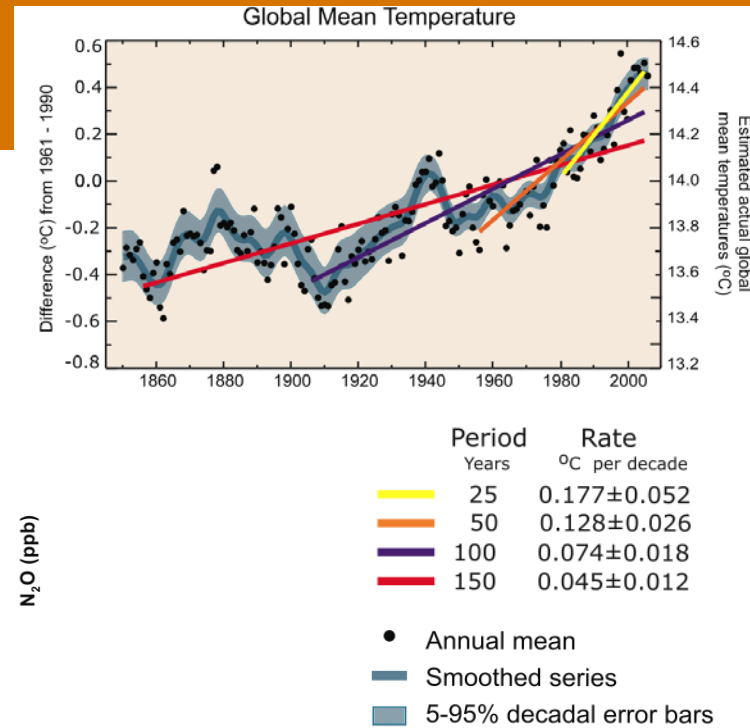
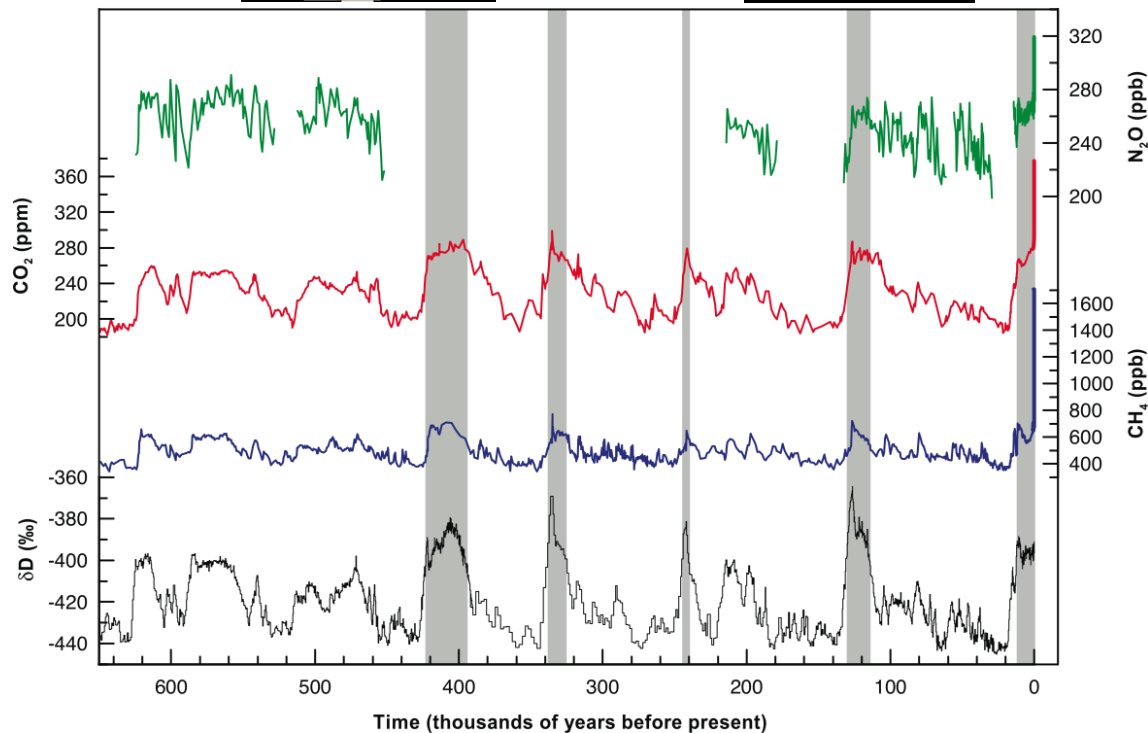
Global warming has not (!) been caused by the precipitous drop in pirates since the beginning of the Industrial Revolution

Climate Change 101

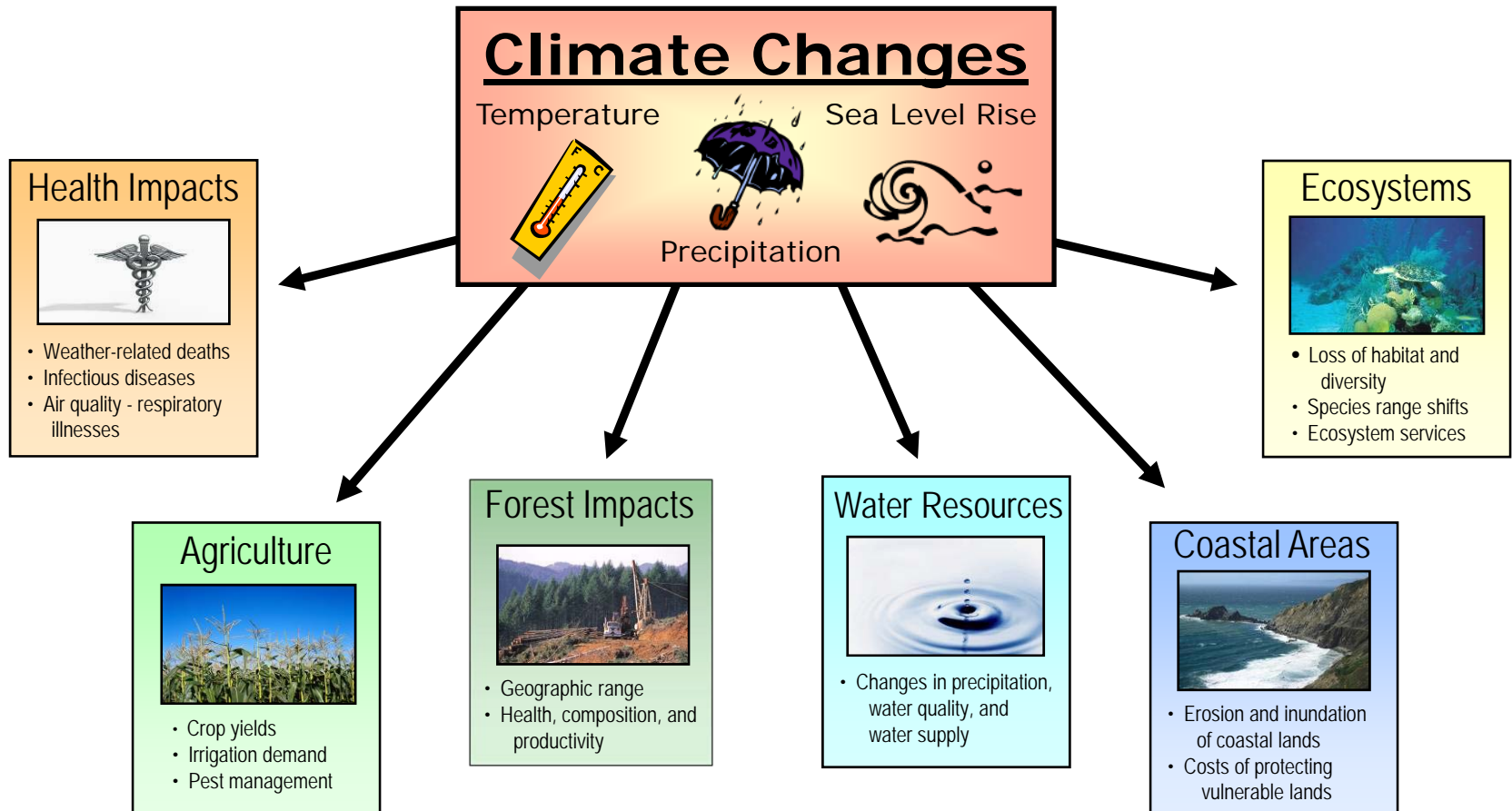
Homo erectus



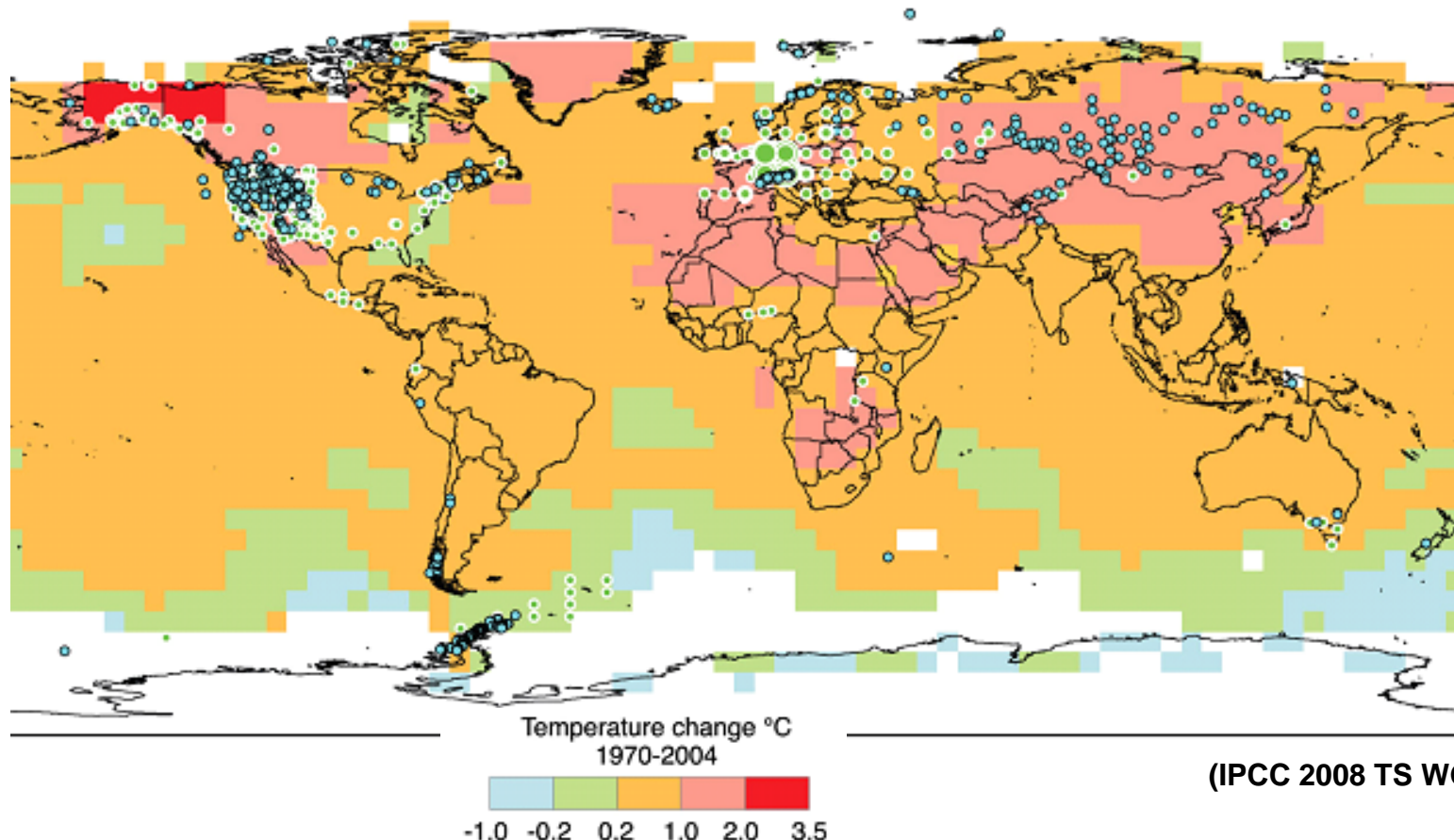
Homo sapiens



“Climate Change” not “Global Warming”



Observed Changes in Physical and Biological Systems and Surface Temperature 1970-2004



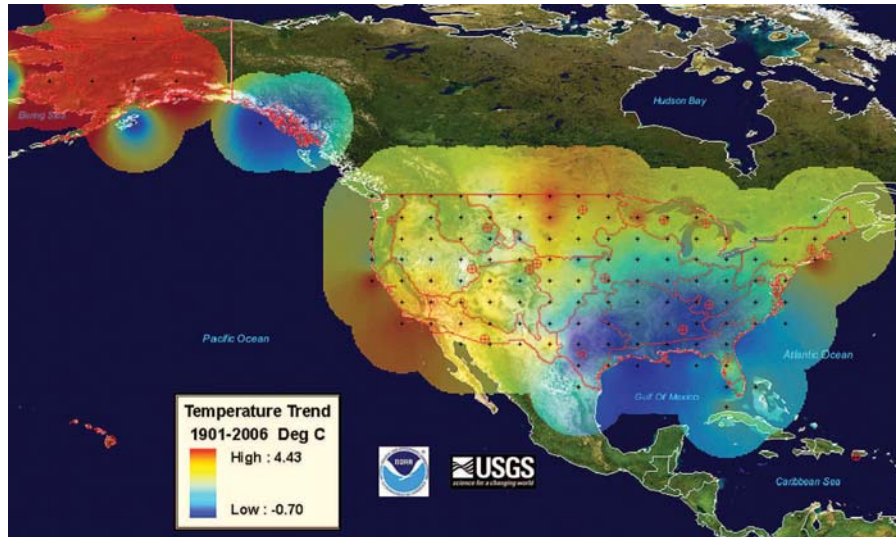
(IPCC 2008 TS WG2)

Observed data series

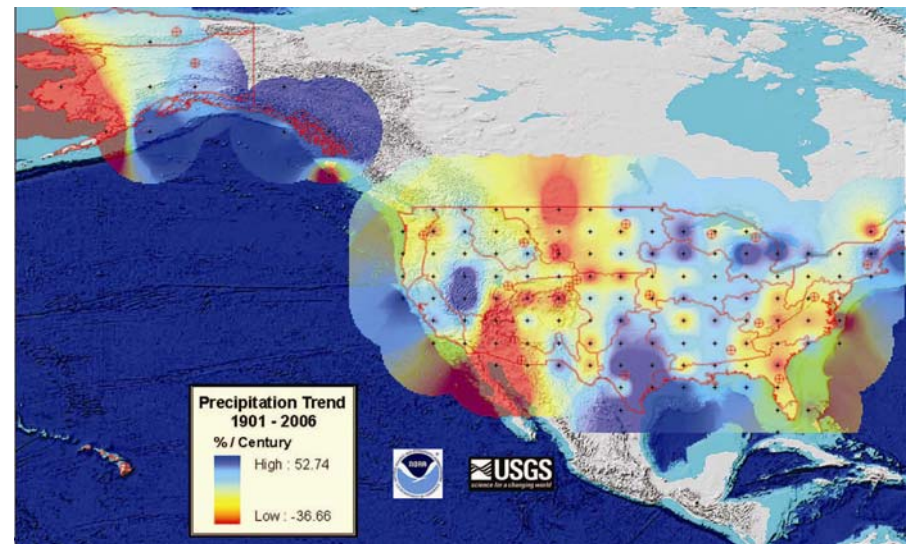
- Physical systems (snow, ice and frozen ground; hydrology; coastal processes)
- Biological systems (terrestrial, marine, and freshwater)

Observed Changes in Temperature and Precipitation in the US 1901-2006

US Temperature Change, 1901-2006

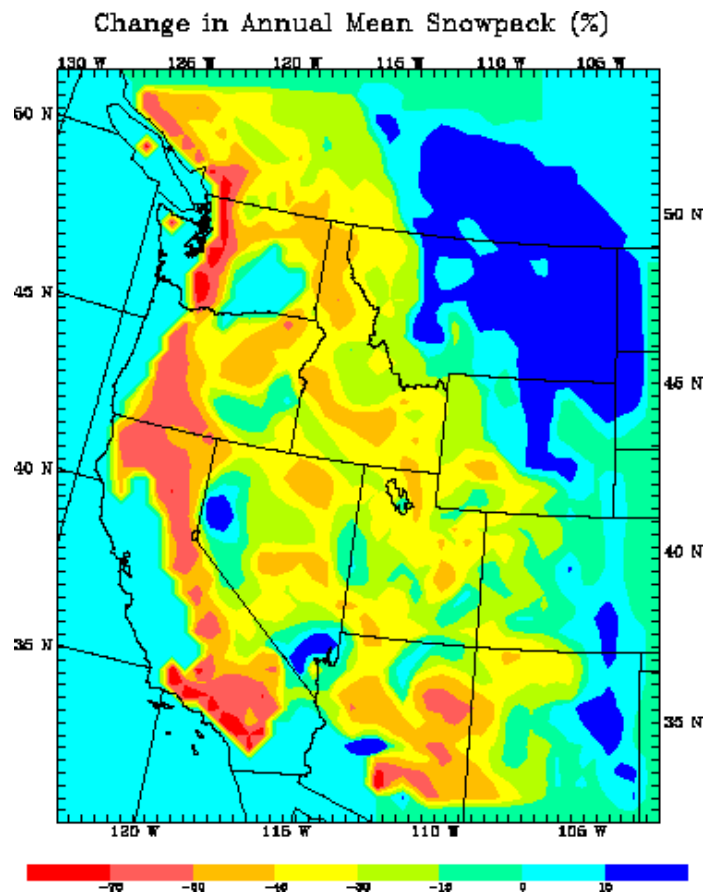


US Precipitation Change, 1901-2006



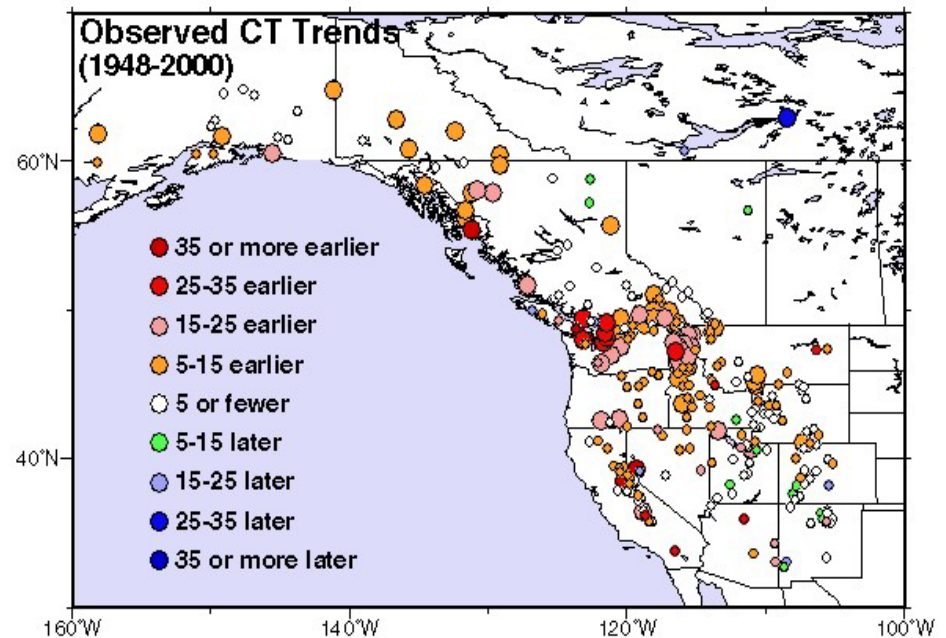
United States Climate Change Science Program. The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States. CCSP Synthesis and Assessment Product 4.3 (May 2008).

Observed Changes in Western U.S. Snowpack



(Leung et al. Climatic Change 2004)

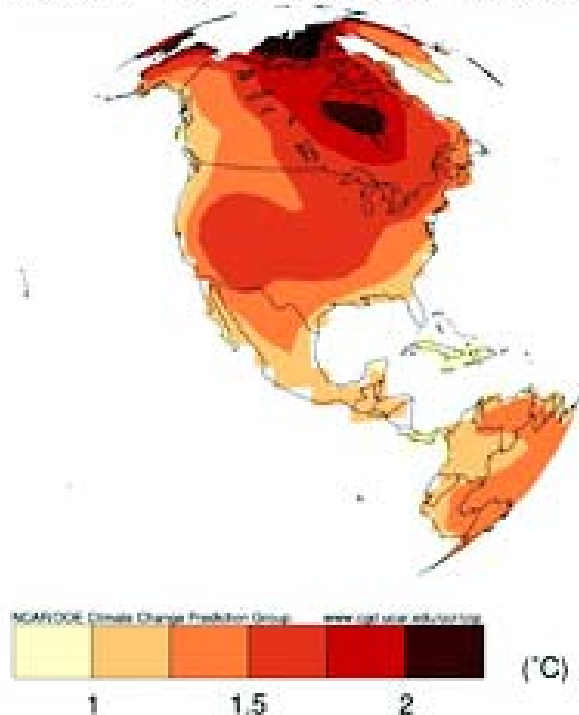
“Center Timing” of many snowmelt watersheds has advanced by 1-4 weeks earlier across the West during last 5 decades



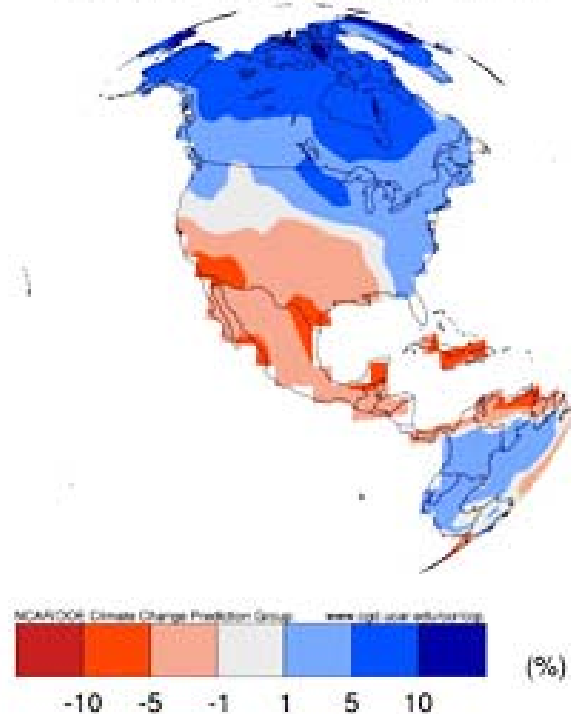
Stewart et. al. 2005

Projected Temperature and Precipitation Changes by 2030

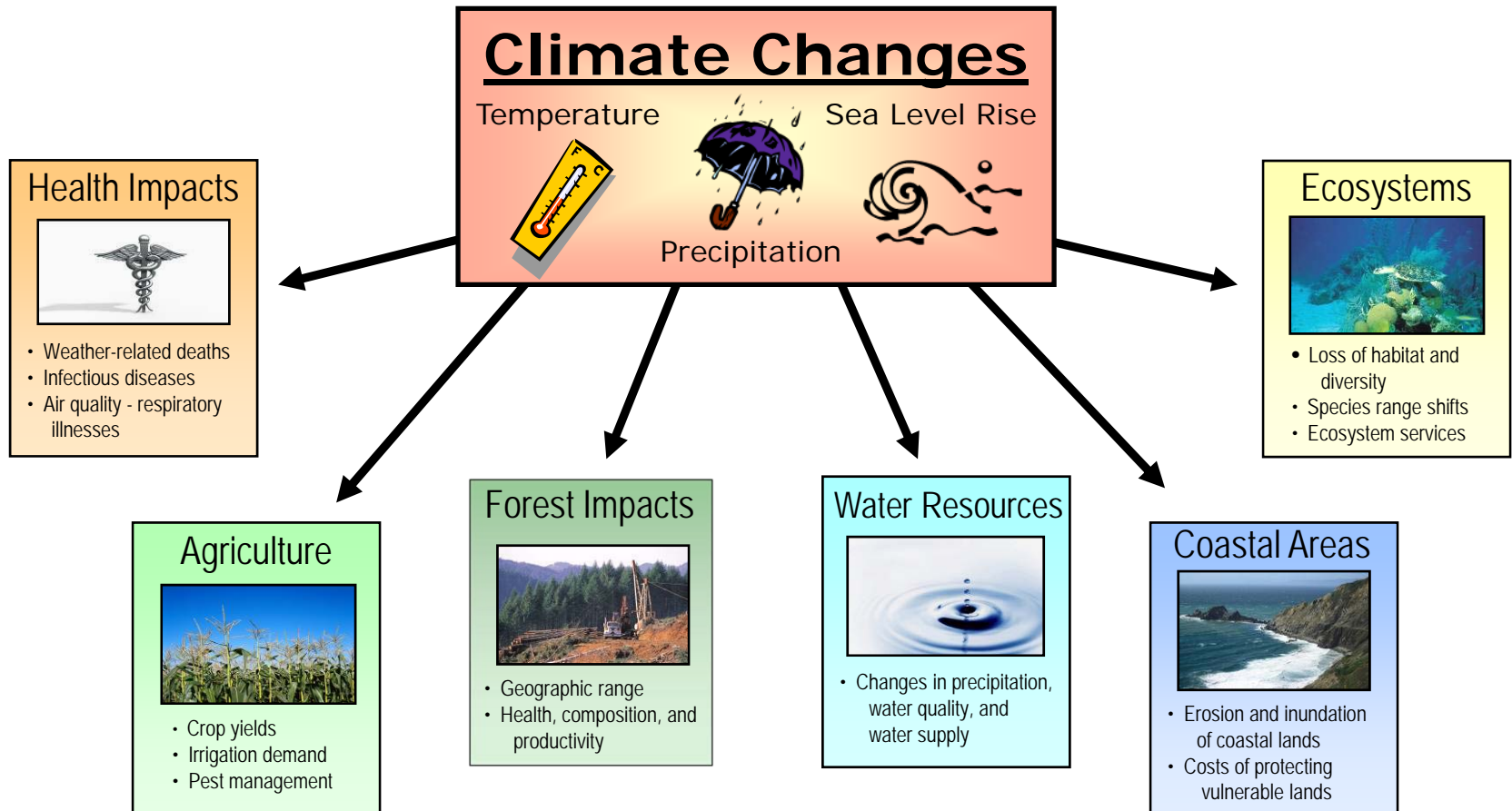
IPCC A1B Sfc Air Temperature 2030-1990



IPCC A1B Precipitation 2030-1990



“Climate Change” not “Global Warming”



Carbon Management Problem Summarized by Article 2 of the United Nations Framework Convention on Climate Change

- ▶ United Nations Framework Convention on Climate Change has nearly 200 member countries, including the United States, and establishes as its “ultimate objective”:

- ...the stabilization of greenhouse gas concentrations...
- ...at a level that would prevent dangerous...interference with the climate system...
- ...and to enable economic development to proceed in a sustainable manner.

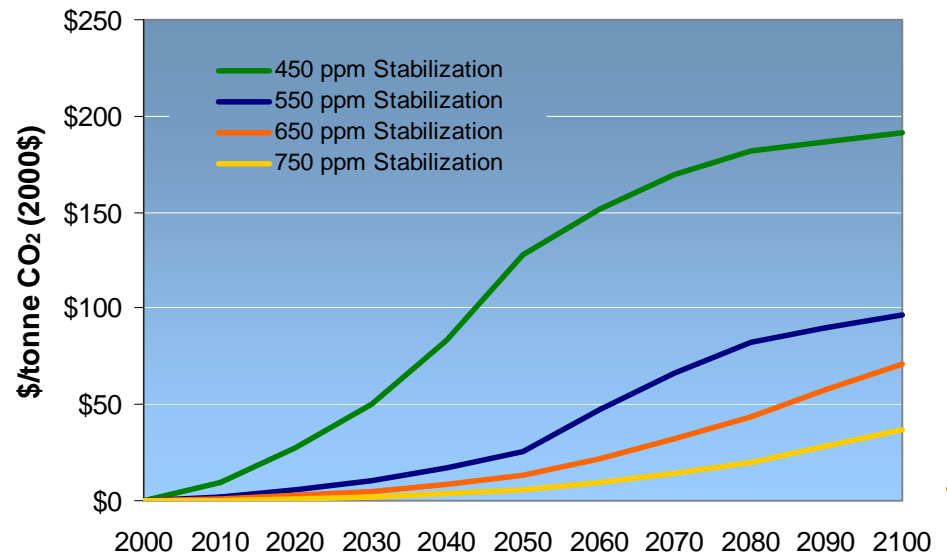
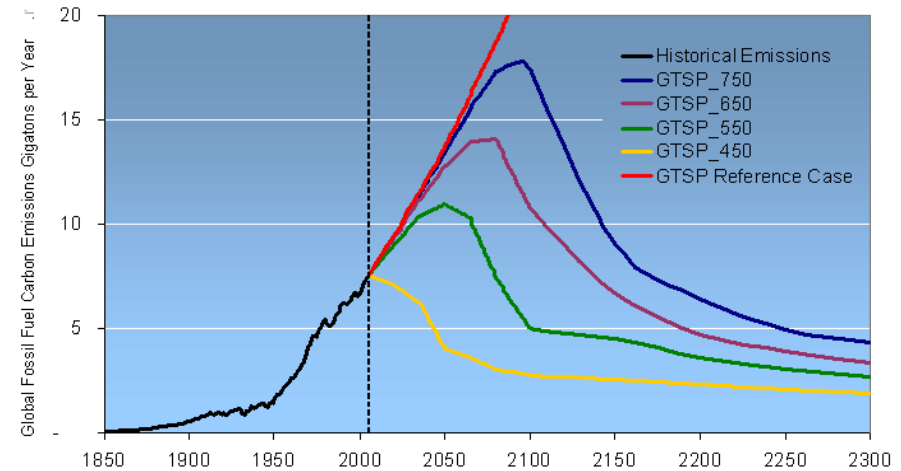
**Concentrations
not
Emissions**

**Don't
Know What is
Dangerous**

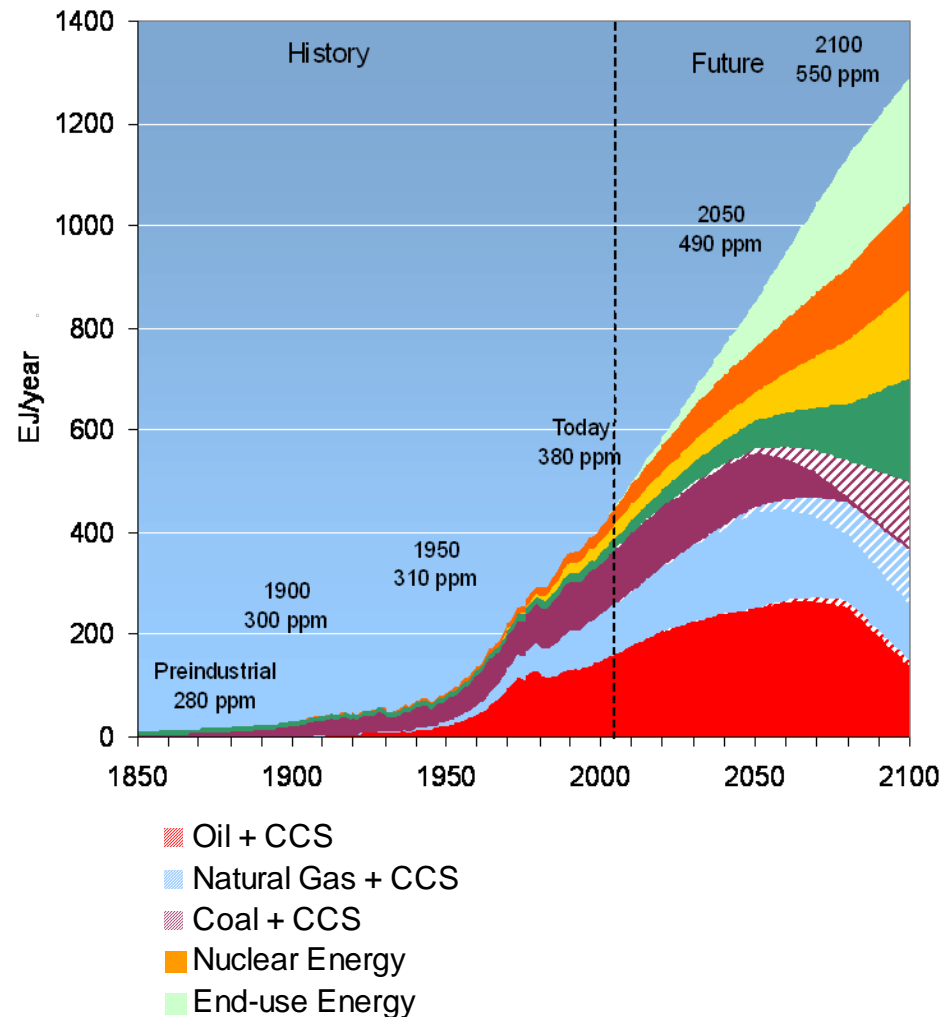
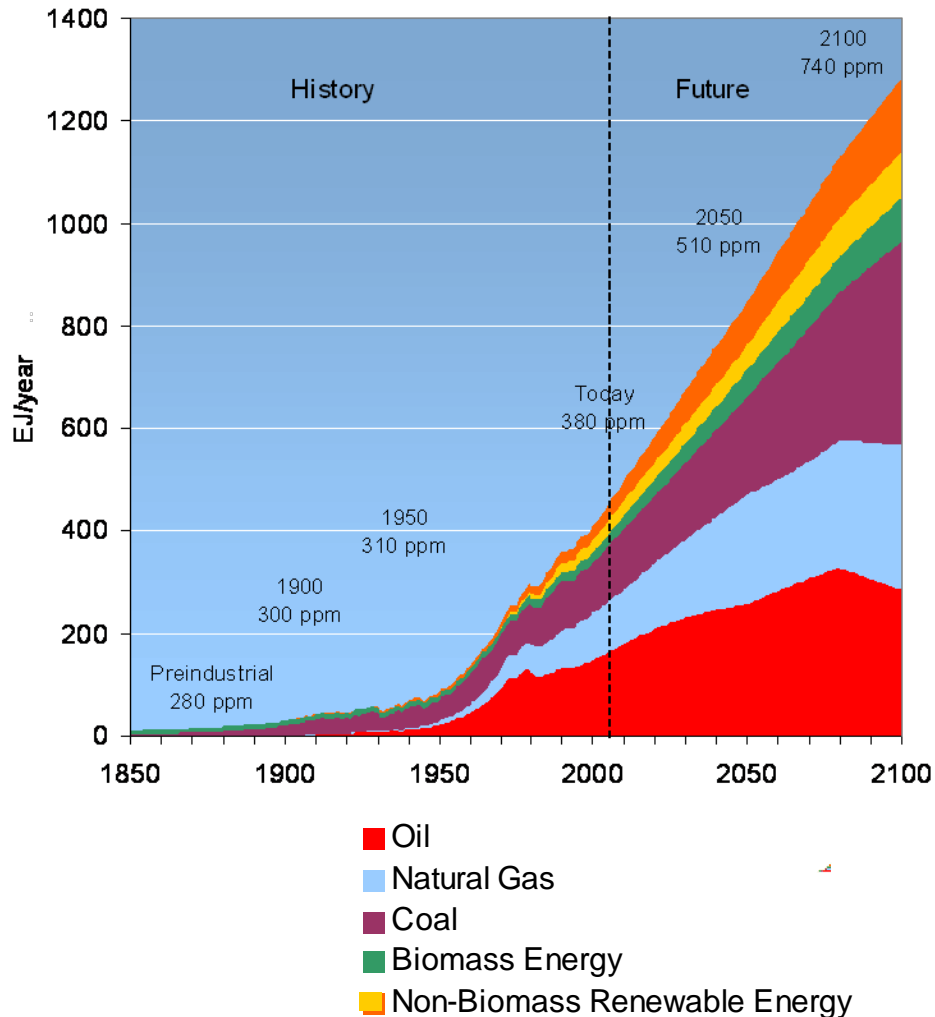
**Economic
Development
Matters**

Climate Change Is a Long-term Strategic Problem with Implications for Today

- ▶ Stabilizing atmospheric concentrations of greenhouse gases and not their annual emissions levels should be the overarching strategic goal of climate policy.
- ▶ This tells us that a fixed and finite amount of CO₂ can be released to the atmosphere over the course of this century.
 - We all share a planetary greenhouse gas emissions budget.
 - Every ton of emissions released to the atmosphere reduces the budget left for future generations.
 - As we move forward in time and this planetary emissions budget is drawn down, the remaining allowable emissions will become more valuable.
 - Emissions permit prices should steadily rise with time.

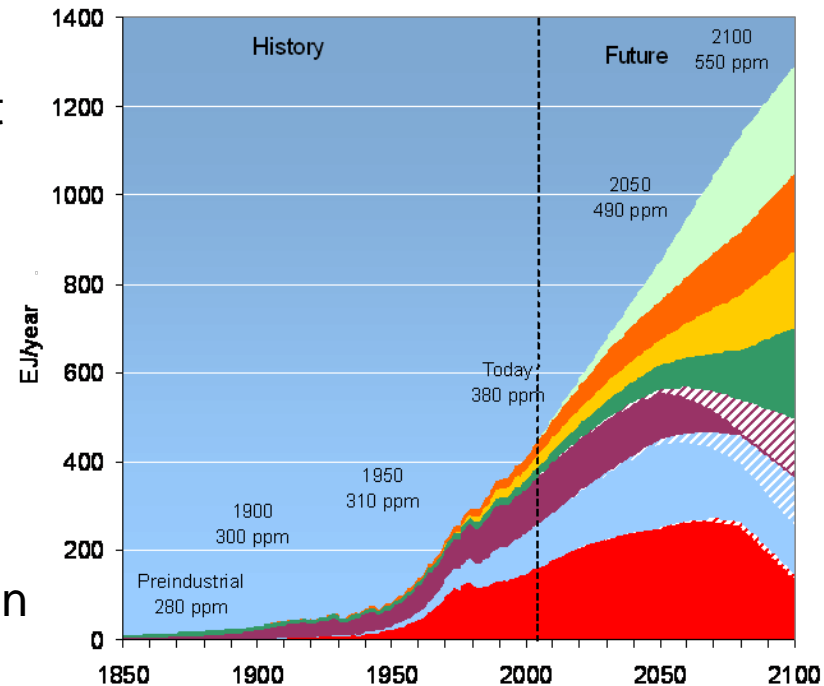


Stabilization of CO₂ Concentrations Means Fundamental Change to the Global Energy System



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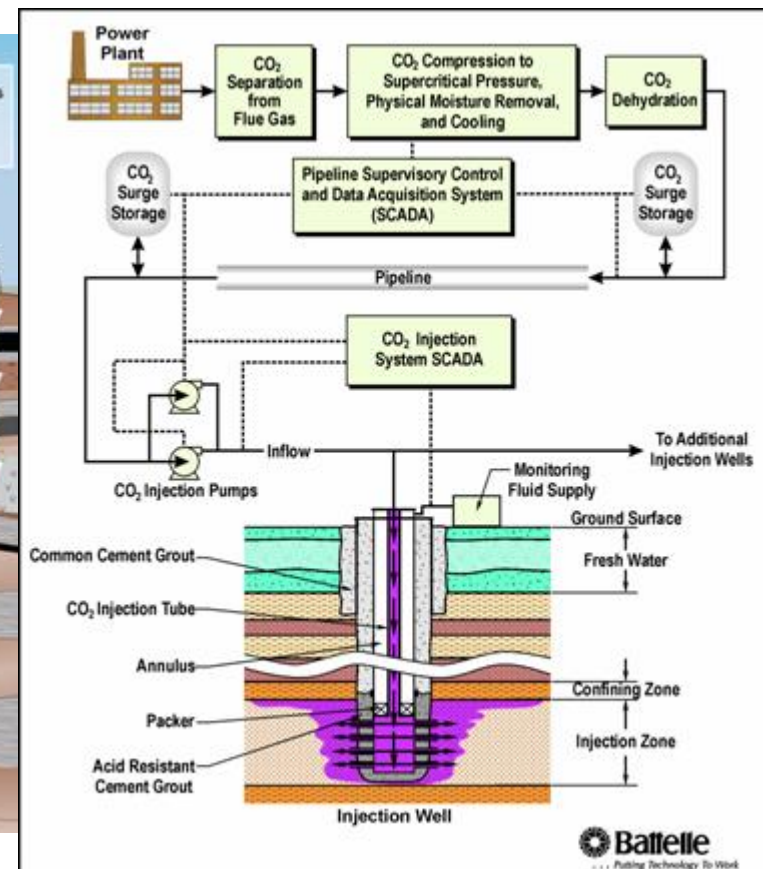
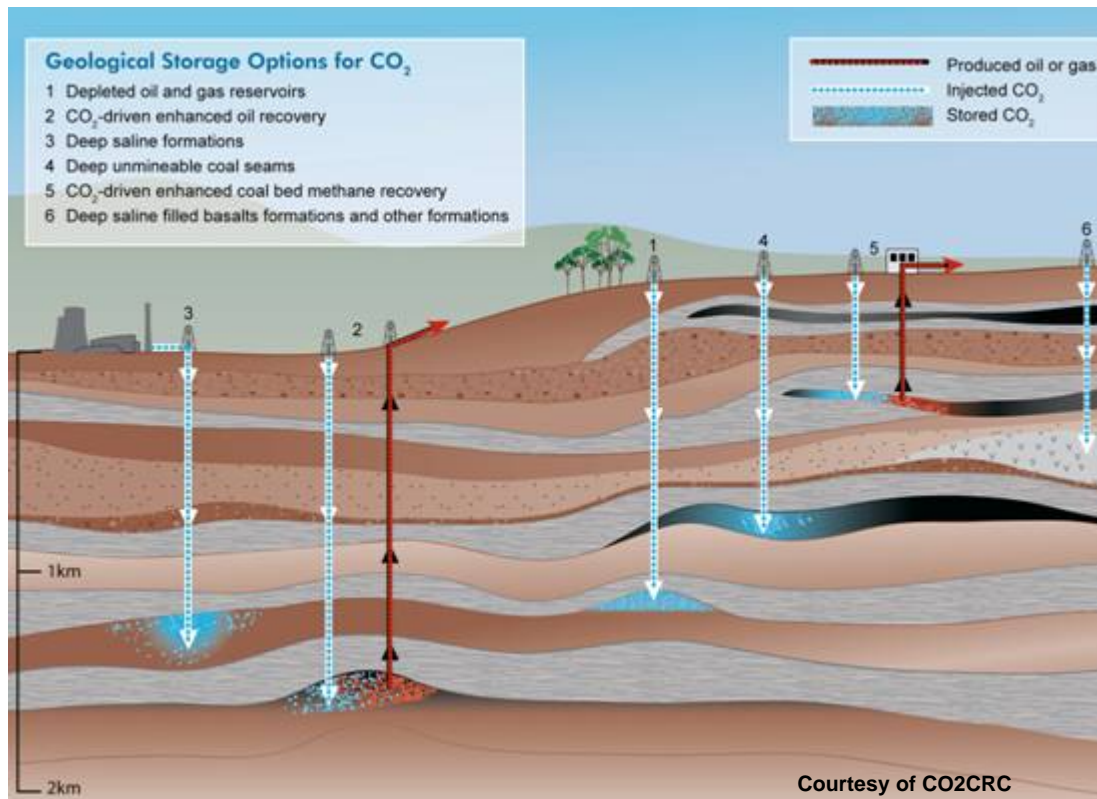
- ▶ CO₂ capture and storage (CCS) plays a potentially large role assuming that the institutions make adequate provision for its use.
- ▶ Bioenergy crops have dramatic potential, but important land-use implications.
- ▶ Hydrogen could be a major new energy carrier, but requires important technology advances in fuel cells and storage.
- ▶ Nuclear energy could deploy extensively throughout the world but public acceptance, institutional constraints, waste, safety and proliferation issues remain.
- ▶ Wind & solar could accelerate their expansion particularly if energy storage improves.
- ▶ End-use energy technologies that improve efficiency and/or use energy carriers with low emissions can also play significant roles, e.g. continued electrification of the global economy.



CO₂ Capture and Storage: Not Nearly this Simple

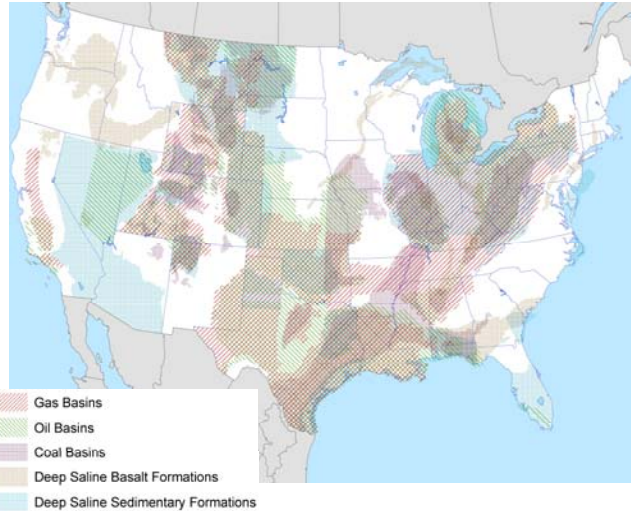


Overview of Carbon Dioxide Capture and Storage



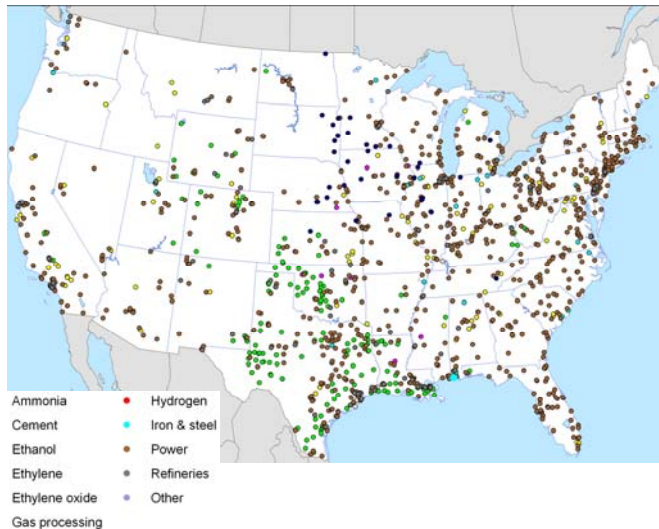
CCS Deployment Across the US Economy

Large CO₂ Storage Resource and Large Potential Demand for CO₂ Storage



3,900+ GtCO₂ Capacity within 230 Candidate Geologic CO₂ Storage Reservoirs

- ▶ 2,730 GtCO₂ in deep saline formations (DSF) with perhaps close to another 900 GtCO₂ in offshore DSFs
- ▶ 240 Gt CO₂ in on-shore saline filled basalt formations
- ▶ 35 GtCO₂ in depleted gas fields
- ▶ 30 GtCO₂ in deep unmineable coal seams with potential for enhanced coalbed methane (ECBM) recovery
- ▶ 12 GtCO₂ in depleted oil fields with potential for enhanced oil recovery (EOR)

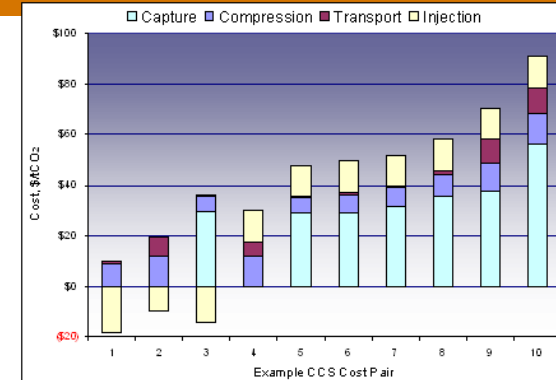
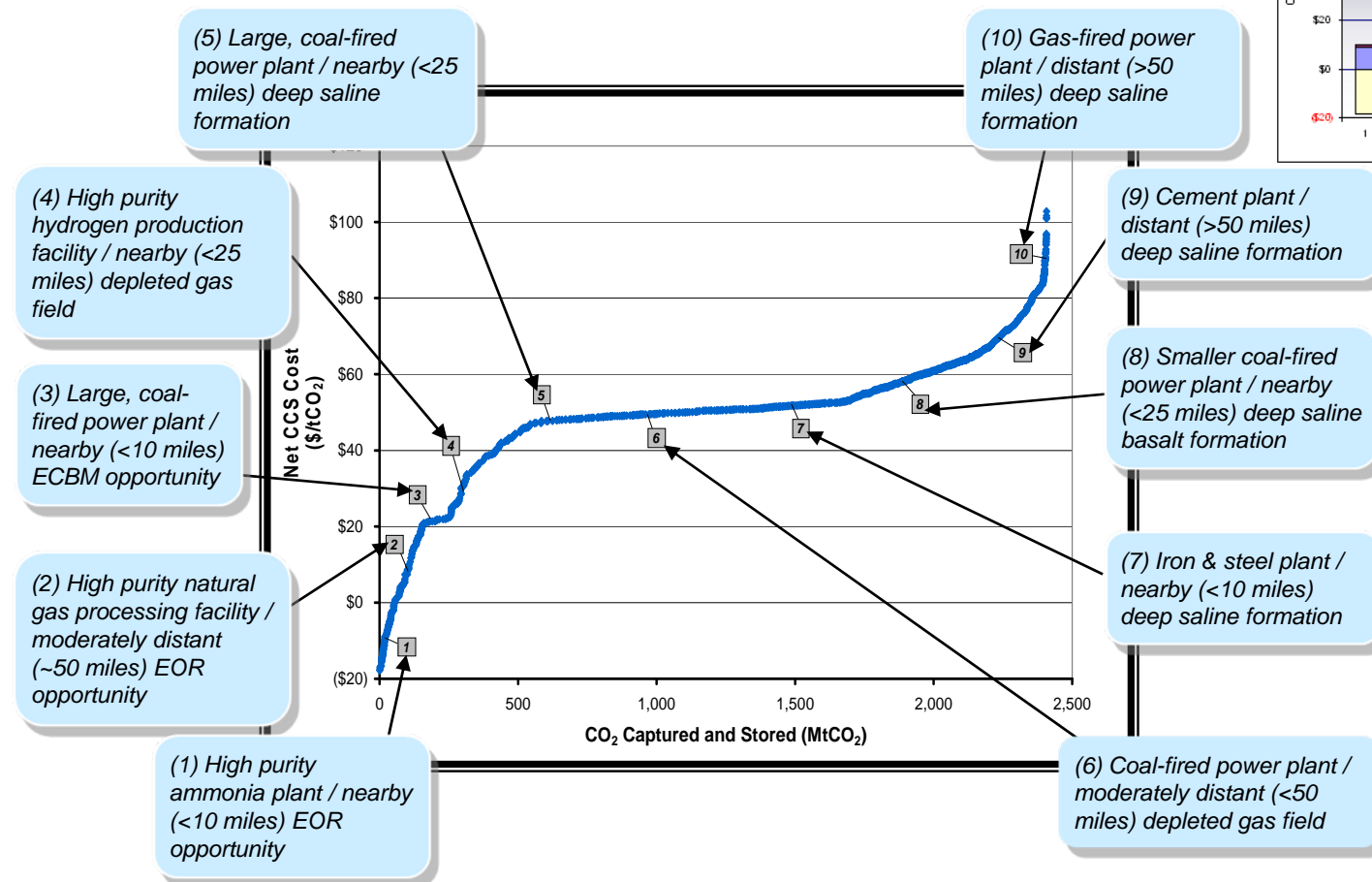


1,715 Large Sources (100+ ktCO₂/yr) with Total Annual Emissions = 2.9 GtCO₂

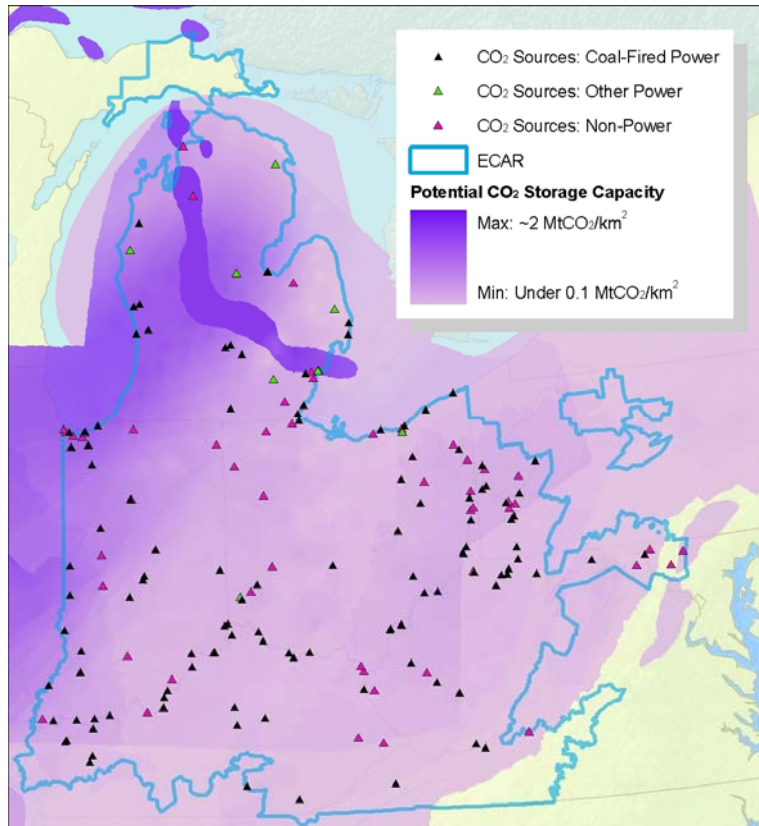
- 1,053 electric power plants
- 259 natural gas processing facilities
- 126 petroleum refineries
- 44 iron & steel foundries
- 105 cement kilns
- 38 ethylene plants
- 30 hydrogen production
- 19 ammonia refineries
- 34 ethanol production plants
- 7 ethylene oxide plants

CCS Deployment Across the US Economy: Differentiated CCS Adoption Across Economic Sectors

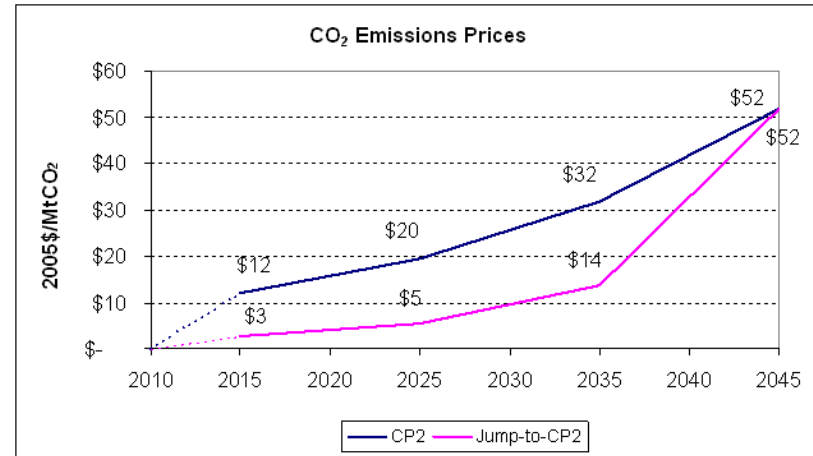
The Net Cost of Employing CCS within the United States - Current Sources and Technology



Uncertainty about Future Greenhouse Gas Constraints Increases the Value of Post-Combustion CCS Technologies



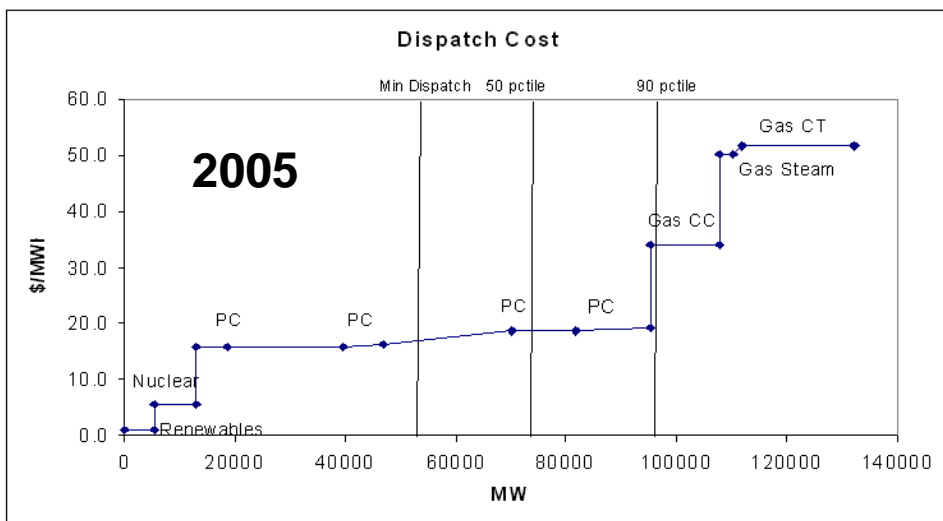
ECAR region, its large, heterogeneous potential geologic storage capacity and large (greater than 0.1 MtCO₂/year) stationary CO₂ emissions point sources by type



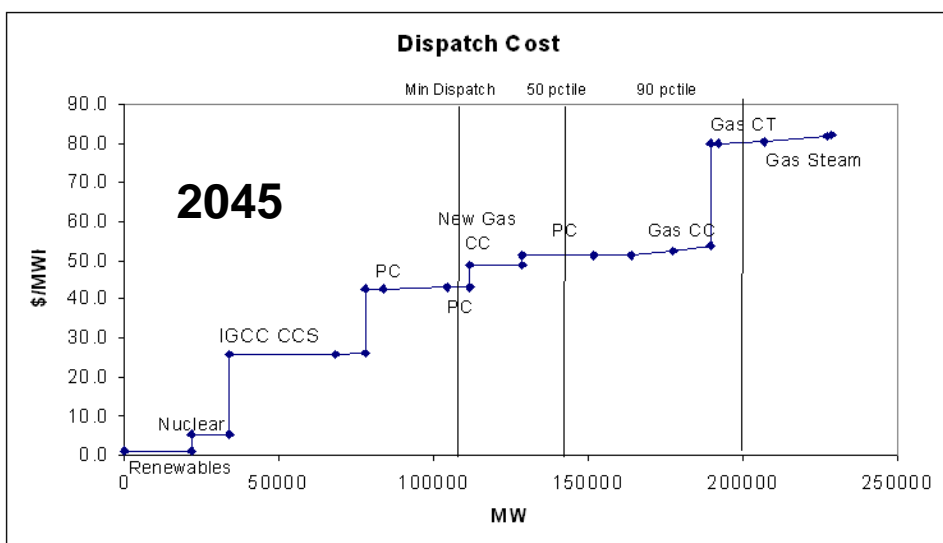
	CP2: Base PC+CCS	CP2: Improved PC+CCS	Jump to CP2: Base PC+CCS	Jump to CP2: Improved PC+CCS
Existing (pre-2005) PC units that are retrofit with CCS by 2045 (GW)	0	22	0	22
New (post-2005 builds) PC units that adopt CCS by 2045 (GW)	0	0	0	17.7
IGCC+CCS by 2045 (GW)	81	70	72	57
Cumulative CO ₂ Stored in ECAR by 2045 (MtCO ₂)	4,300	4,900	3,200	3,600

CCS Deployment by Electric Utilities

IGCC+CCS and Nuclear Are Keys to Decarbonizing Baseload Power

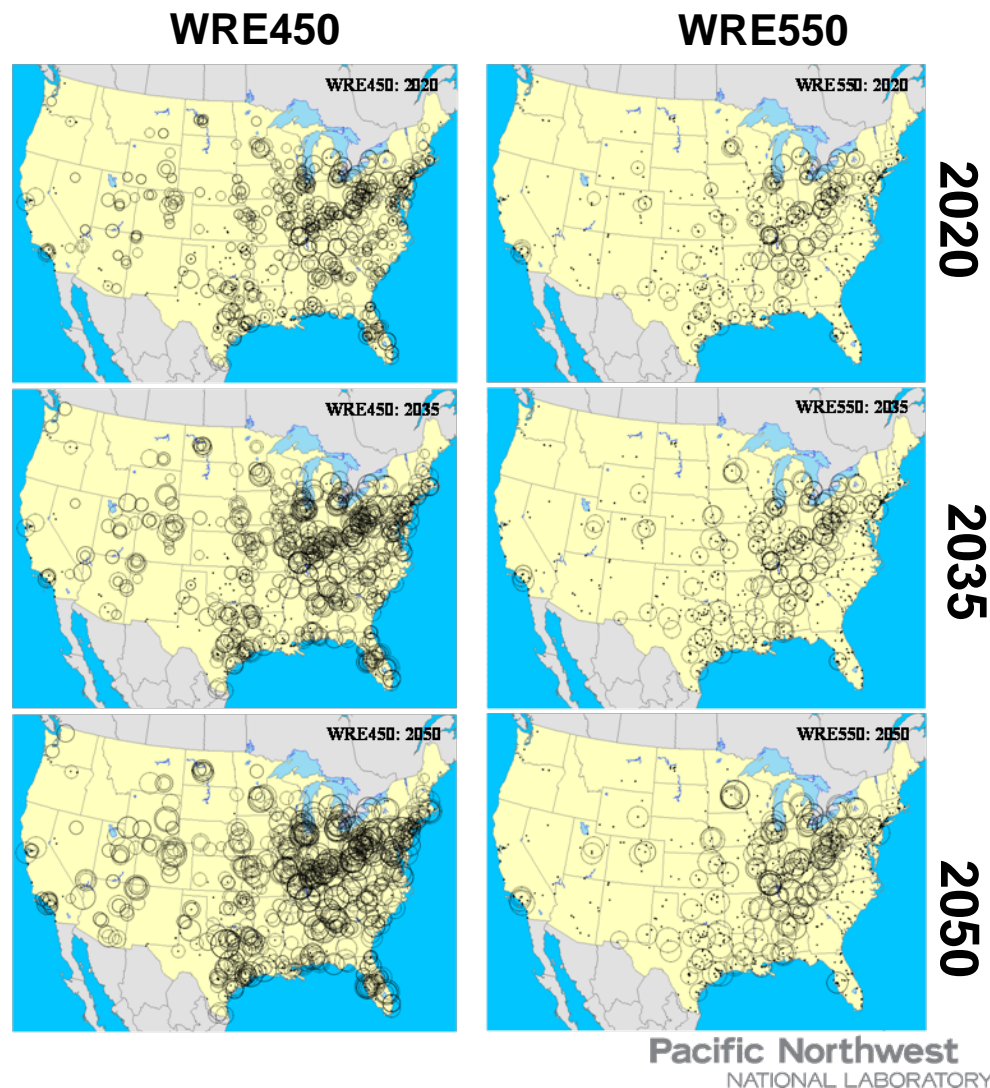


- ▶ In 2005, conventional fossil-fired power plants were the predominant means of generating competitively priced electricity.
- ▶ However, given today's and (likely) tomorrow's higher natural gas prices and the imposition of a hypothetical binding greenhouse gas control policy,
 - While renewables are likely to grow substantially, IGCC+CCS and nuclear become -- in some regions of the U.S. -- the dominant means of generating low-carbon *baseload* electricity.

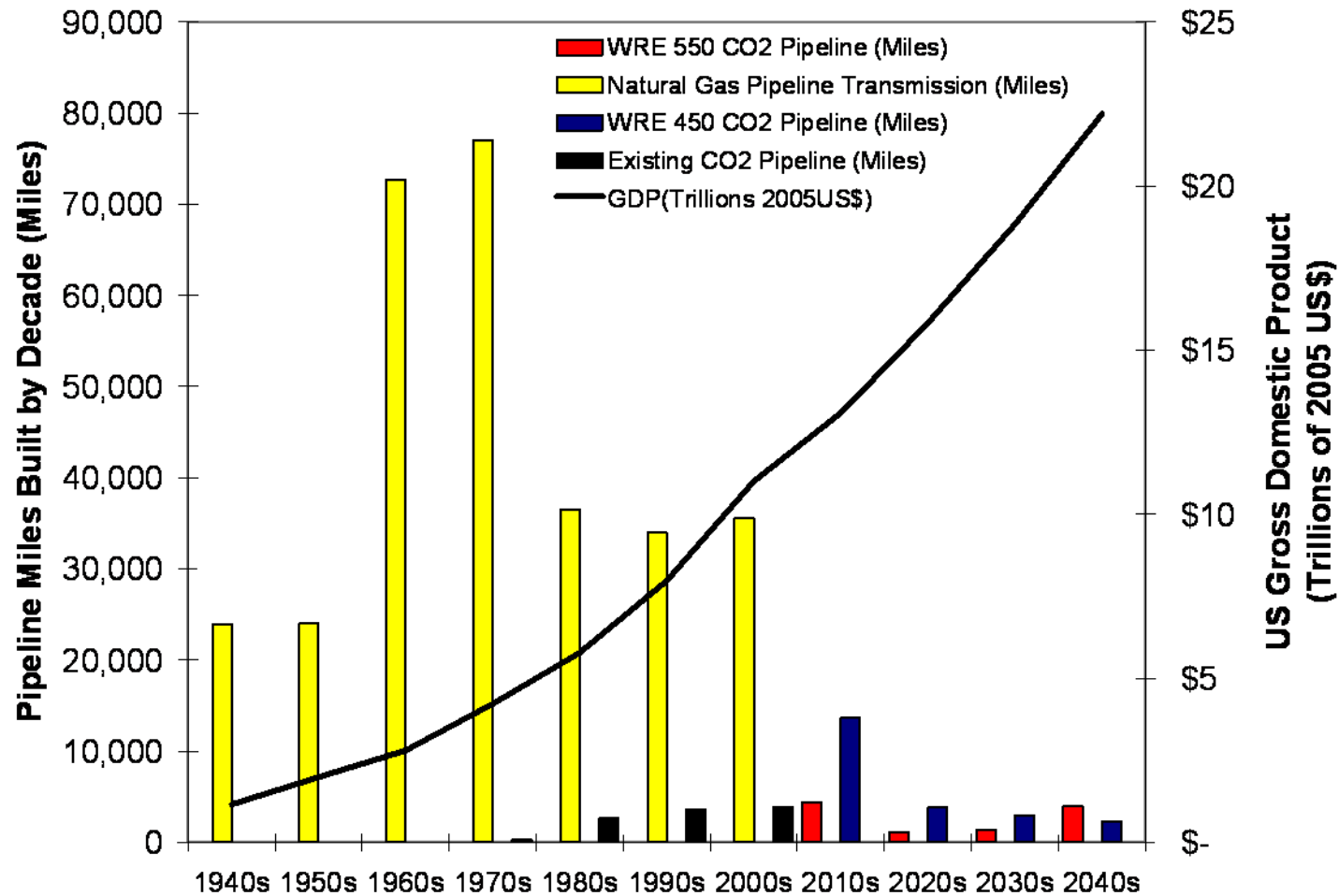


The Principal Role for CCS in the U.S. Is to Help Decarbonize the Electric Utility Sector

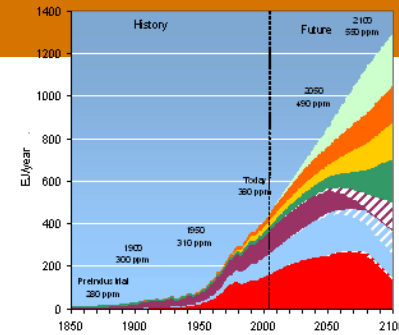
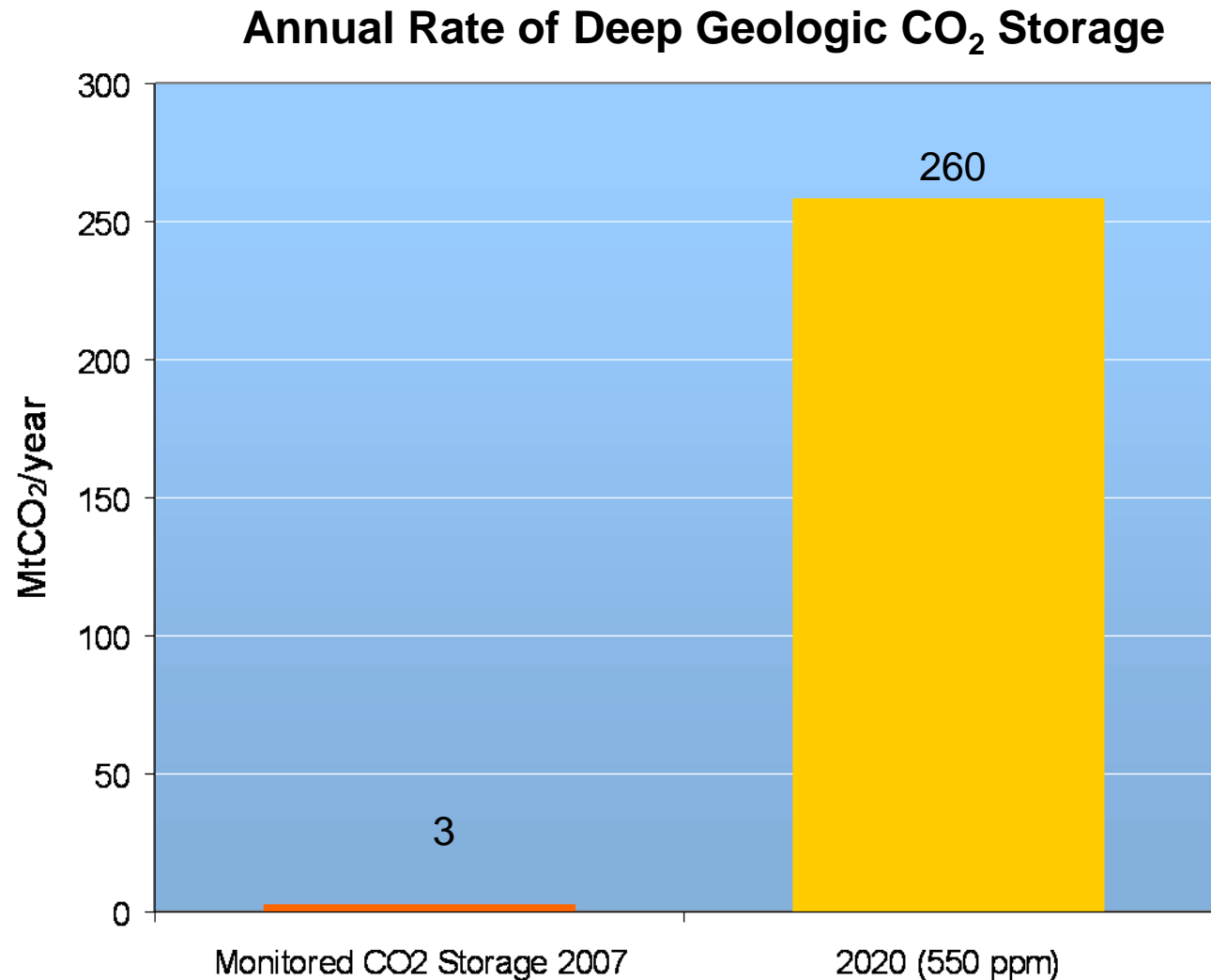
- ▶ It is important to realize that we are in the earliest stages of the deployment of CCS technologies.
- ▶ The potential deployment of CCS technologies could be truly massive. The potential deployment of CCS in the US could entail:
 - 1,000s of power plants and industrial facilities capturing CO₂, 24-7-365.
 - 10,000s of miles of dedicated CO₂ pipelines.
 - 100s of millions of tons of CO₂ being injected into the subsurface annually.



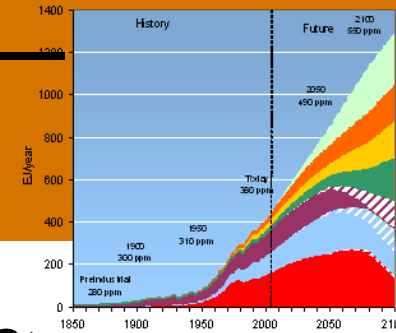
Comparing the Existing U.S. Natural Gas Pipeline Transmission System, Potential Future CCS-Driven CO₂ Pipeline Systems and the Size of U.S. Economy



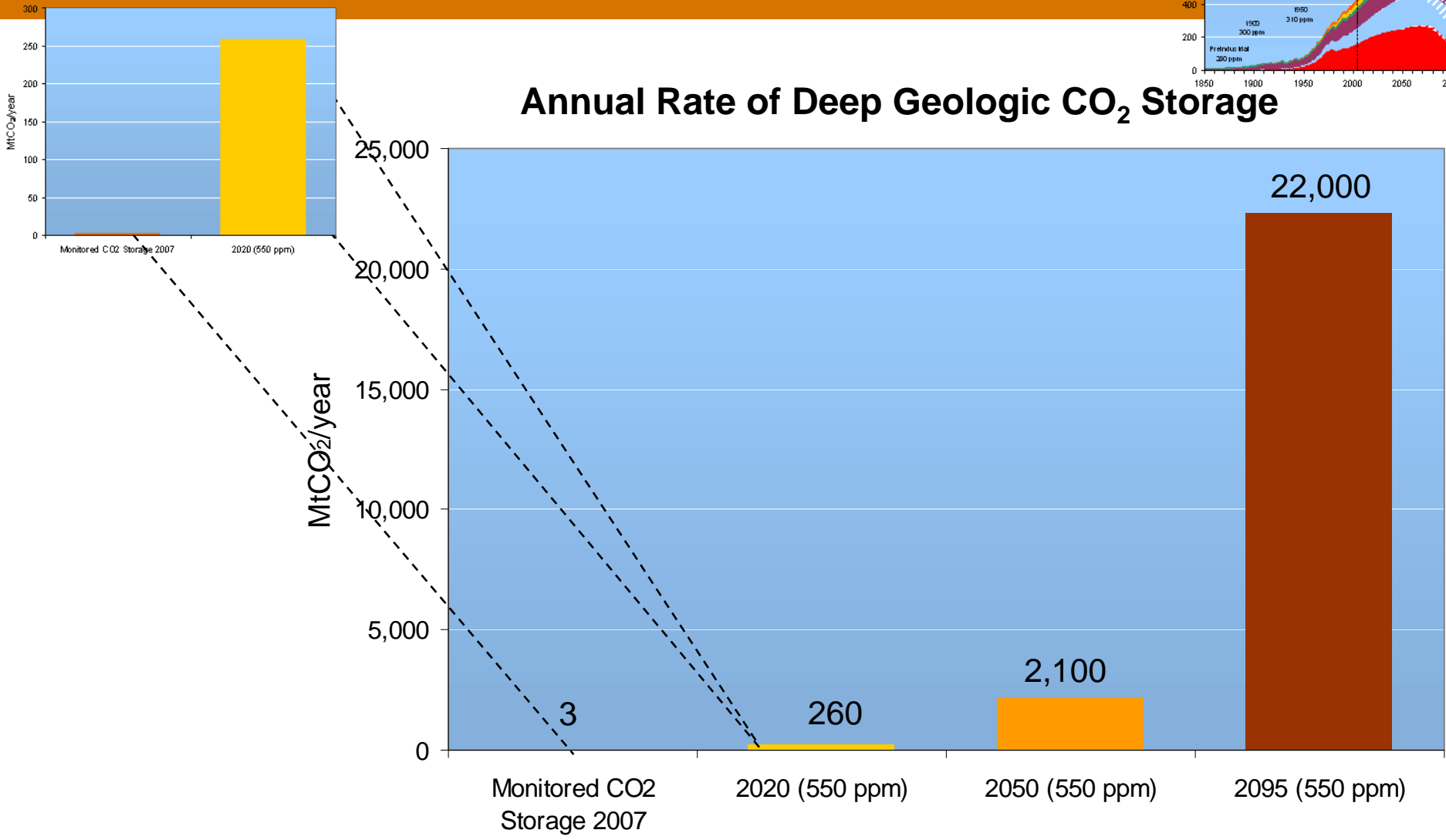
The Challenge of Scale Grows with Time — the near term



The Challenge of Scale Grows with Time — the mid to long term

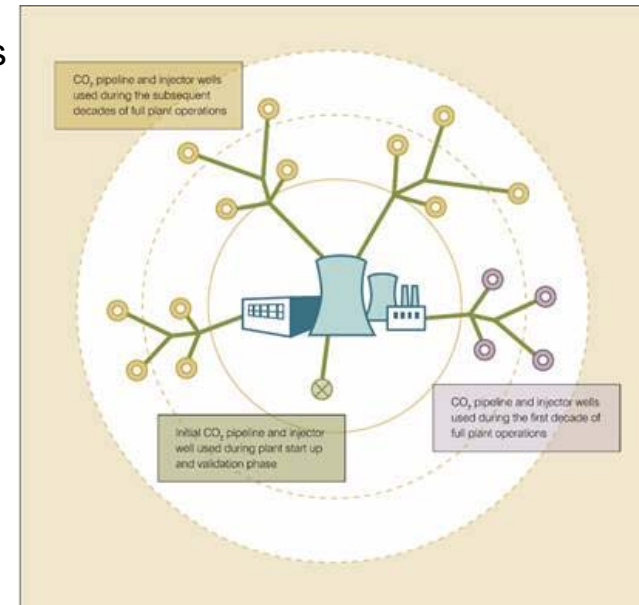


Annual Rate of Deep Geologic CO₂ Storage



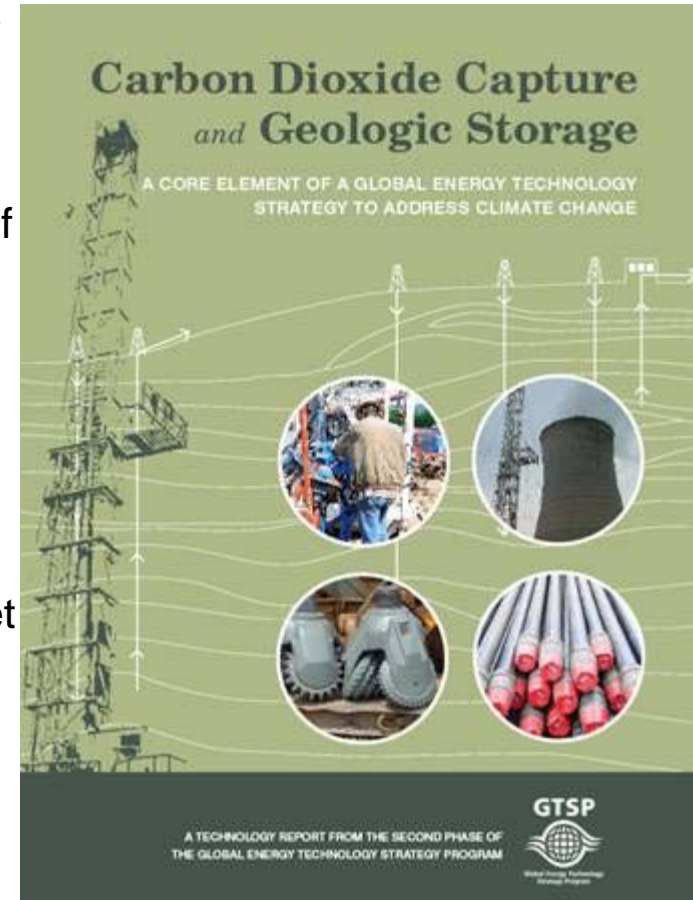
Experiential Knowledge Is Needed to Move CCS Forward

- ▶ The cost of capturing CO₂ is **not** the single biggest obstacle standing in the way of CCS deployment.
- ▶ When thinking about storing 100% of a large power plant's emissions for 50+ years, there are a number of things that we would like to know today but are likely to only learned through real world operational experience:
 - Can the same injector wells be used for 50+ years?
 - Are the operational characteristics that make a field a good candidate CO₂-driven enhanced oil recovery similar to the demands placed upon deep geologic formation that is being used to isolate large quantities of CO₂ from the atmosphere for the long term?
 - What measurement, monitoring and verification (MMV) “technology suites” should be used and does the suite vary across different classes of geologic reservoirs and/or with time?
 - How long should post injection monitoring last?
 - What are realistic, field deployable remediation options if leakage from the target storage formation is detected?
 - Who will regulate CO₂ storage on a day-to-day basis? What criteria and metrics will this regulator use?



GTSP Phase II Capstone Report on Carbon Dioxide Capture and Storage

- ▶ CCS technologies have tremendous potential value for society.
- ▶ CCS is, at its core, a climate-change mitigation technology and therefore the large-scale deployment of CCS is contingent upon the timing and nature of future GHG emission control policies.
- ▶ The next 5-10 years constitute a critical window in which to amass needed real-world operational experience with CCS systems.
- ▶ The electric power sector is the largest potential market for CCS technologies and its potential use of CCS has its own characteristics that need to be better understood.
- ▶ Much work needs to be done to ensure that the potential large and rapid scale-up in CCS deployment will be safe and successful.



Climate Change Is a Long-term Strategic Problem with Implications for Today

- ▶ Climate change is a long-term, century scale, problem that ultimately implies a fundamental transformation of the global energy and economic system but that also has implications for today.
- ▶ Technology is essential to addressing climate change and controlling the cost of doing so.
- ▶ There is no “silver bullet” for addressing climate change nor is there a “silver bullet” for managing the negative consequences of a changing climate.
- ▶ A strategy to address climate change while *simultaneously* meeting all of society’s other goals and aspirations must include:
 - Development and subsequent global commercial deployment of advanced, cleaner energy technologies
 - Continued scientific research on the climate system and impacts
 - Emissions limitations
 - Adaptation to climate change.
- ▶ There are many strategies for managing the risks posed by climate change. It is collectively up to us to put the best possible strategy on the table.